HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

SEMI-ANNUAL TECHNICAL PROGRESS REPORT
April 6 - September 5, 2000

by

Thomas C. Chidsey, Jr., Principal Investigator/Program Manager,
Utah Geological Survey
David E. Eby, Eby Petrography & Consulting, Inc.
and
Laura L. Wray, Colorado Geological Survey

February 2001

Contract No. DE-FC26-00BC15128

Gary D. Walker, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101-3628

DISCLAIMER

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CONTENTS

FIGURES

TABLES

ABSTRACT

The Paradox basin of Utah, Colorado, Arizona, and New Mexico contains nearly 100 small oil fields producing from carbonate buildups within the Pennsylvanian (Desmoinesian) Paradox Formation. These fields typically have one to 10 wells with primary production ranging from 700,000 to 2,000,000 barrels (111,300-318,000 m^3) of oil per field and a 15 to 20 percent recovery rate. At least 200 million barrels (31,800,000 m^3) of oil will not be recovered from these small fields because of inefficient recovery practices and undrained heterogeneous reservoirs. Several fields in southeastern Utah and southwestern Colorado are being evaluated for horizontal drilling from existing vertical field wells based upon geological characterization and reservoir modeling case studies. The results of these studies can be applied to similar fields in the Paradox basin and the Rocky Mountain region, the Michigan and Illinois basins, and the Midcontinent region.

Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization, within Cherokee and Bug fields in Utah. This study utilizes representative core and geophysical logs to characterize and grade each field's potential for drilling horizontal laterals from existing development wells. The typical vertical sequence or cycle of lithofacies from each field, as determined from conventional core, is being tied to its corresponding log response using a detailed log-based correlation scheme. From these evaluations, untested or under-produced compartments will be identified as targets for horizontal drilling.

Technology transfer activities consisted of exhibiting a booth display of project materials at the annual national convention of the American Association of Petroleum Geologists. Project team members met with the Technical Advisory and Stake Holders Boards to introduce the project and present project goals. Project presentations were made to the U.S. Department of Energy Contractors Review Meeting and the 10th Annual National Indian Energy & Minerals Conference sponsored by the Bureau of Indian Affairs. A project home page was developed for the Utah Geological Survey and Colorado Geological Survey Internet web sites.

EXECUTIVE SUMMARY

The project's primary objective is to enhance domestic petroleum production by demonstration and transfer of horizontal drilling technology in the Paradox basin, Utah, Colorado, Arizona, and New Mexico. If this project can demonstrate technical and economic feasibility, then the technique can be applied to approximately 100 additional small fields in the Paradox basin alone, and result in increased recovery of 25 to 50 million barrels (40-80 million m^3) of oil. This project is designed to characterize several shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation, choose the best candidate(s) for a pilot demonstration project to drill horizontally from existing vertical wells, monitor well performance(s), and report associated validation activities.

The Utah Geological Survey heads a multidisciplinary team to determine the geological and reservoir characteristics of typical small shallow-shelf carbonate reservoirs in the Paradox basin. The Paradox basin technical team consists of the Utah Geological Survey (prime contractor), Colorado Geological Survey, Eby Petrography & Consulting Inc., and Seeley Oil Company. This research is performed with funding from the Class II Oil Revisit Program of the U.S. Department of Energy, National Petroleum Technology Office (NPTO) in Tulsa, Oklahoma. This report covers research and technology transfer activities for the first half of the first project year (April 6 through September 5, 2000). This work includes description and analysis of cores from the Cherokee and Bug fields in Utah, determination of depositional environments, and development of a detailed log-based correlation scheme to help determine reservoir heterogeneity of these fields. From these evaluations, untested or under-produced reservoir compartments can be identified as targets for horizontal drilling. The results can be applied to similar reservoirs in many U.S. basins.

Reservoir data (porosity and permeability), cores and cuttings, geophysical logs, various reservoir maps, and other information from the case-study fields and adjacent regional exploratory wells are being collected. Well locations, production reports, completion tests, core analysis, formation tops, and other data are being compiled and entered in a database developed by the Utah Geological Survey. Core photographs and descriptions are being compiled for case-study field wells with special emphasis on identifying bounding surfaces of possible flow units and depositional environments. Typical vertical sequences or cycles of lithofacies from each field, as determined from conventional core, are being tied to corresponding geophysical log responses.

Technology transfer activities consisted of exhibiting a booth display of project materials at the annual national convention of the American Association of Petroleum Geologists. Technical team members met with the Technical Advisory and Stake Holders Boards to introduce the project and project goals. Project presentations were made to the U.S. Department of Energy Contractors Review Meeting and the 10th Annual National Indian Energy & Minerals Conference sponsored by the Bureau of Indian Affairs. A project home page was developed for the Utah Geological Survey and Colorado Geological Survey Internet web sites. The project team members submitted an abstract to the American Association of Petroleum Geologists for a poster and core presentation during the 2001 annual national convention in Denver, Colorado. Newsletters were published with an overview of the project.

INTRODUCTION

Geologic Setting

The Paradox basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongued with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

The Paradox basin can generally be divided into two areas: the Paradox fold and fault belt in the north, and the Blanding sub-basin in the south-southwest (figure 1). Most oil production is found in the Blanding sub-basin. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996). The relatively undeformed Blanding sub-basin developed on a shallow-marine shelf which locally contained algal-mound and other carbonate buildups in a subtropical climate.

The two main producing zones are informal zones of the Paradox Formation, the Ismay and the Desert Creek. The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material with locally variable small-scale subfacies capped by anhydrite. The Ismay produces oil from fields in the southern Blanding sub-basin (figure 2). The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts. The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 2). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

Project Overview

Over 400 million barrels of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian Paradox Formation in the Paradox basin. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short production life (primary), and hence premature

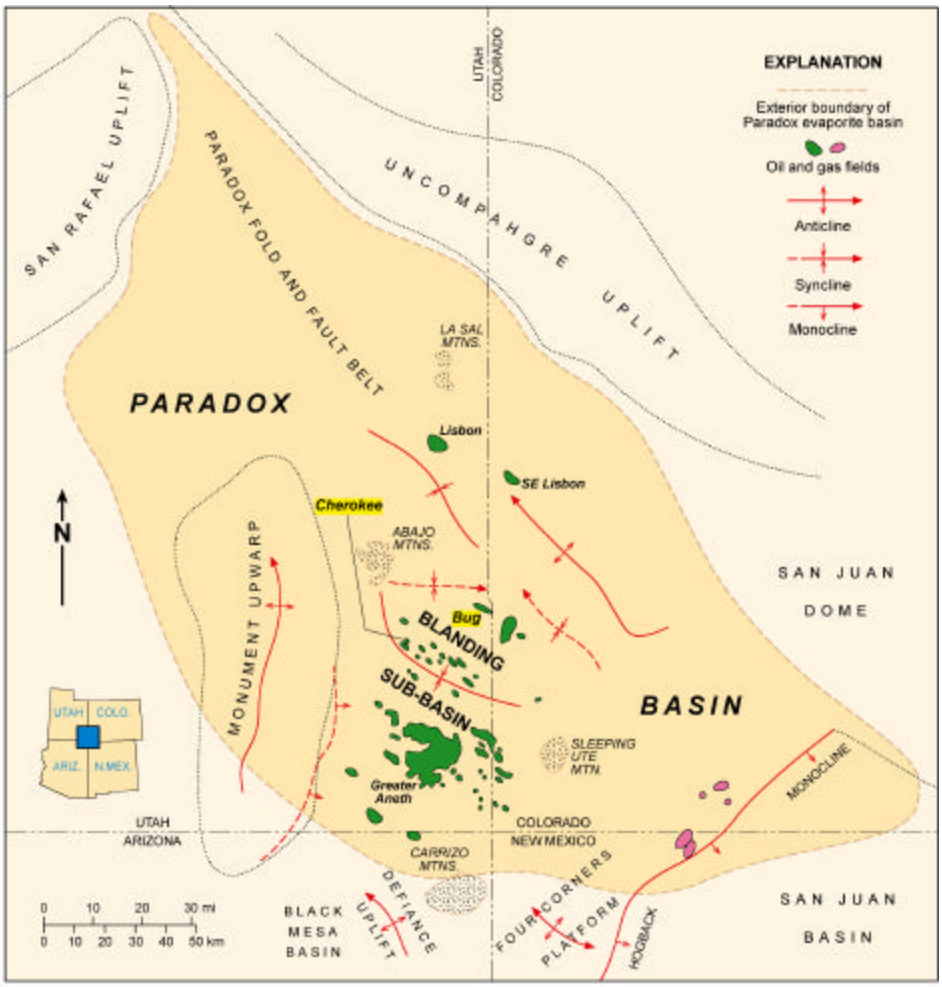


Figure 1. Location map of the Paradox basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical development wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in the small Ismay and Desert Creek fields. The results from these wells were disappointing as a result of poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs (figure 3) from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

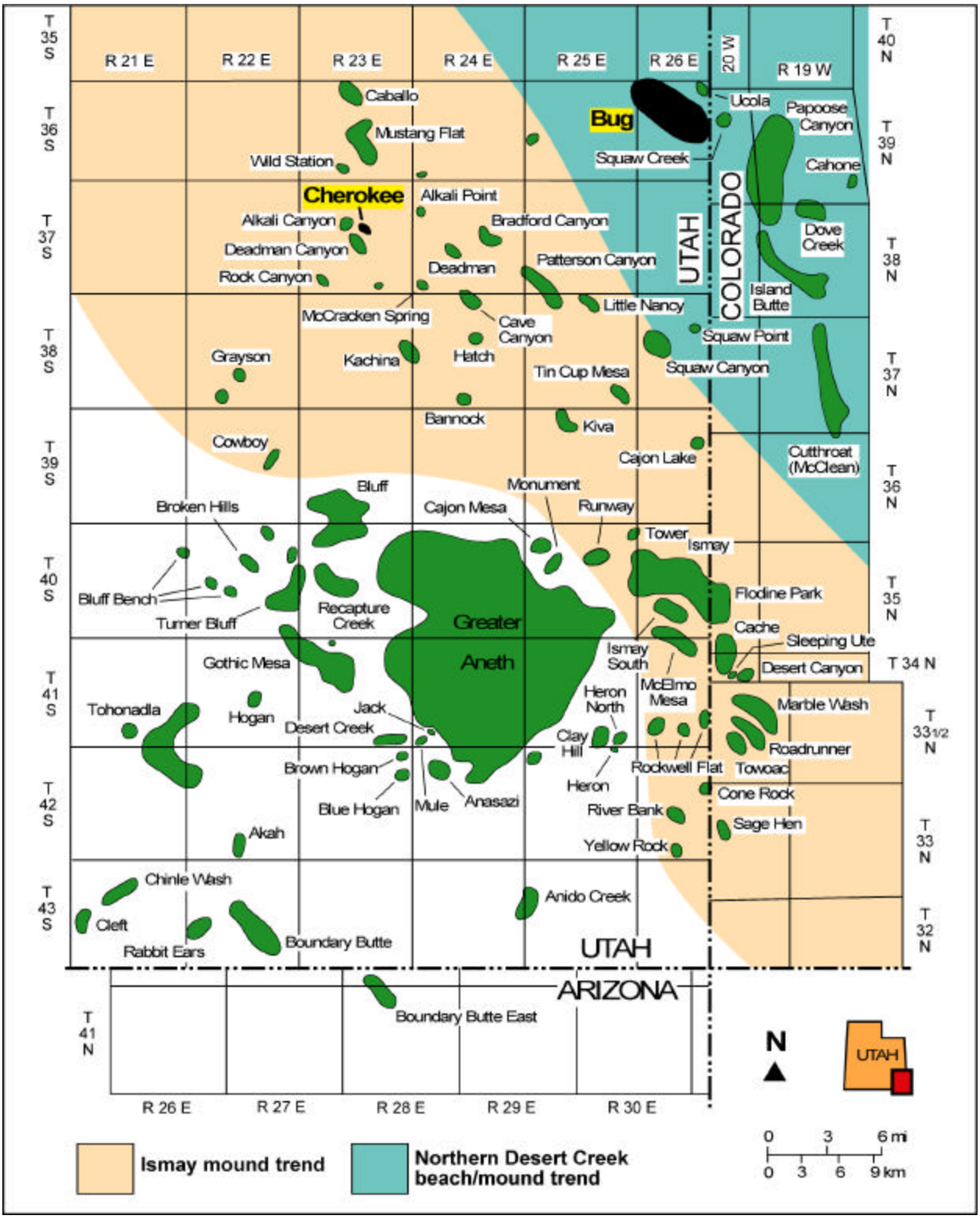


Figure 2. Map showing the project study area and fields within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado. Fields shown in the white area of the map, including the giant Greater Aneth field, produce primarily from the Desert Creek zone on the shelf margin of the Paradox basin.

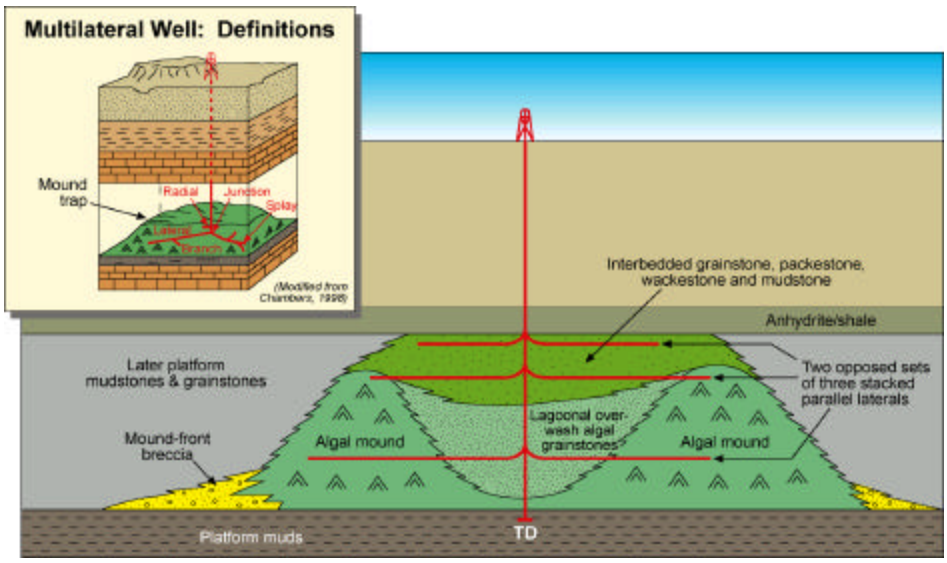


Figure 3. Schematic diagram of Ismay zone drilling targets by multilateral (horizontal) legs from an existing field well.

The Utah Geological Survey (UGS), Colorado Geological Survey (CGS), Eby Petrography & Consulting, Inc., and Seeley Oil Company have entered into a cooperative agreement with the U.S. Department of Energy as part of its Class II Oil Revisit Program. A three-phase, multidisciplinary approach will be used to increase production and reserves from the shallow-shelf carbonate reservoirs in the Ismay and Desert Creek zones of the Paradox basin. Phase 1 will be the geological and reservoir characterization of selected, diversified small fields, including Cherokee and Bug fields in San Juan County, Utah (figure 2), to identify those field(s) having the greatest potential as targets for increased well productivity and ultimate recovery in a pilot demonstration project. This phase will include: (a) determination of regional geological setting; (b) analysis of the reservoir heterogeneity, quality, lateral continuity, and compartmentalization within the fields; (c) construction of lithologic, microfacies, porosity, permeability, and net pay maps of the fields; (d) determination of field reserves and recovery; and (e) integration of geological data in the design of single or multiple horizontal laterals from existing vertical wells.

Phase 2 will be a field demonstration project of the horizontal drilling techniques identified as having the greatest potential for increased field productivity and ultimate recovery. The demonstration project will involve drilling one or more horizontal laterals from the existing vertical field well(s) to maximize production from the zones of greatest potential.

Phase 3 will include: (a) reservoir management and production monitoring, (b) economic evaluation of the results, and (c) determination of the ability to transfer project technologies to other similar fields in the Paradox basin and throughout the U.S.

Phases 1, 2, and 3 will have continuous, but separate, technical transfer activities including: (a) an industry outreach program and project newsletters; (b) a core workshop/ seminars in Salt Lake City; (c) publications and technical presentations; (d) a project home page on the Utah Geological Survey and Colorado Geological Survey Internet web sites; (e) digital databases, maps, and reports; (f) a summary of regulatory, economic, and financial needs; and (g) annual meetings with a Technical Advisory Board and Stake Holders Board.

Project Benefits and Potential Application

The benefit of this multi-year project would be enhanced domestic petroleum production by demonstrating and transferring an advanced-oil-recovery technology throughout the small oil fields of the Paradox basin. The benefits expected from the project are: (1) increasing recovery and reserve base by identifying untapped compartments created by reservoir heterogeneity; (2) preventing premature abandonment of numerous small fields; (3) increasing deliverability by horizontally drilling along the reservoir's optimal fluid-flow paths; (4) identifying reservoir trends for field extension drilling and stimulating exploration in Paradox basin fairways; (5) reducing development costs by more closely delineating minimum field size and other parameters necessary for horizontal drilling; (6) allowing for minimal surface disturbance by drilling from existing vertical field wells; (7) allowing limited energy investment dollars to be used more productively; and (8) increasing royalty income to the Federal, State, and local governments, the Ute Mountain Ute Indian Tribe, and fee owners. These benefits may also apply to other areas including: algal-mound and carbonate buildup reservoirs on the eastern and northwest shelves of the Permian Basin in Texas, Silurian pinnacle and patch reefs of the Michigan and Illinois basins, and shoaling carbonate island trends of the Williston basin.

The results of this project are transferred to industry and other researchers through establishment of technical advisory and stake holders boards, an industry outreach program, digital project databases, and web page. Project results will be disseminated via technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and papers in newsletters and various technical or trade journals.

GEOLOGICAL CHARACTERIZATION OF CASE-STUDY FIELDS, SAN JUAN COUNTY, UTAH - RESULTS AND DISCUSSION

Two Utah fields were selected for local-scale evaluation during Budget Period I of the project: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 2); others may be evaluated later. This evaluation included data collection, core photography and description, determination of depositional environments, and development of a detailed log-based correlation scheme to help determine reservoir heterogeneity of these fields. This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

Case-Study Fields

Cherokee Field

Cherokee field (figure 2) is a phylloid-algal buildup capped by anhydrite that produces from porous algal limestone and dolomite in the Ismay zone. The net reservoir thickness is 27

feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base and Meridian (SLBL&M); initial flowing potential was 53 barrels of oil per day (BOPD) (8.4 m^3), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 m^3). There are currently four producing (or shut-in) wells and two dry holes in the field. The well spacing is 80 acres (32 ha). The present reservoir field pressure is estimated at 150 pounds per square inch (psi) (1,034 kpa). Cumulative production as of October 1, 2000, was 180,174 barrels of oil (28,648 m^3), 3.59 billion cubic feet of gas (BCFG) (0.1 BCMG), and 1,313 barrels of water (209 m^3) (Utah Division of Oil, Gas and Mining, 2000). The original estimated primary recovery was 172,000 barrels of oil (27,348 m^3) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

Bug Field

Bug field (figure 2) is an elongate, northwest-trending carbonate buildup in the Desert Creek zone. The producing units vary from porous dolomitized bafflestone to packstone and wackestone. The trapping mechanism is an updip porosity pinchout. The net reservoir thickness is 15 feet (4.6 m) over a 2,600-acre (1,052 ha) area. Porosity averages 11 percent in moldic, vuggy, and intercrystalline networks. Permeability averages 25 to 30 md, but ranges from less than 1 to 500 md. Water saturation is 32 percent (Martin, 1983; Oline, 1996).

Bug field was discovered in 1980 with the completion of the Wexpro Bug No. 1, NE1/ SE1/4 section 12, T. 36 S., R. 25 E., SLBL&M, for an initial flowing potential of 608 BOPD (96.7 m^3), 1,128 MCFGPD (32 MCMPD), and 180 barrels of water (28.6 m^3). There are currently eight producing (or shut-in) wells, five abandoned producers, and two dry holes in the field. The well spacing is 160 acres (65 ha). The present reservoir field pressure is 3,550 psi (24,477 kpa). Cumulative production as of October 1, 2000, was 1,613,872 barrels of oil (256,606 m^3), 4.33 BCFG (0.12 BCMG), and 3,159,256 barrels of water (502,322 m^3) (Utah Division of Oil, Gas and Mining, 2000). Estimated primary recovery is 1,600,000 bbls (254,400 m^3) of oil and 4 BCFG (0.1 BCMG) (Oline, 1996). Again, since the original reserve estimates have been surpassed and the field is still producing, significant additional reserves likely remain.

Field Data Collection and Compilation

Reservoir data, cores and cuttings, geophysical logs, various reservoir maps, and other information from the project fields and regional exploratory wells are being collected by the UGS and CGS. Well locations, production data, completion tests, basic core analysis, formation tops, and other data are being compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS Access™ . The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment can be exported to software programs to produce strip logs, lithofacies maps, various graphs, statistical

models, and other types of presentations. The database containing information on the geological and reservoir characterization study will be available at the UGS and CGS Paradox basin project Internet web site at the conclusion of the project.

All available conventional cores from the Cherokee and Bug fields, as well as two Colorado wells, were photographed (figures 4 and 5) and described (figures 6 and 7, and table 1). Special emphasis was placed on identifying the flow unit's bounding surfaces and depositional environments. The core descriptions follow the guidelines of Bebout and Loucks (1984) which include: (1) basic porosity types; (2) mineral composition in percentage; (3) nature of contacts; (4) carbonate structures; (5) carbonate textures in percentage; (6) carbonate fabrics; (7) grain size (dolomite); (8) fractures; (9) color; (10) fossils; (11) cement; and (12) depositional environment. Carbonate fabrics were determined according to Dunham's (1962) and Embry and Klovan's (1971) classification schemes. Representative samples were selected from the cores for later thin section description and possible geochemical analysis to determine diagenetic history and pore types. From initial observations, the quality of reservoir units in these fields has been affected by multiple generations of dissolution, anhydrite plugging, and various types of cementation which act as barriers or baffles to fluid flow.

Depositional Environments

A preliminary determination of the Ismay and Desert Creek depositional environments was made based on the core descriptions. These are shown schematically on figure 8. The controls on the development of each depositional environment (lithofacies) were water depth, salinity, prevailing wave energy, and paleostructural position. In Cherokee field, the following depositional facies are recognized: open-marine shelf, organic buildups and calcarenites at the platform edge; middle shelf or open platform interior; and restricted inner shelf or platform interior. In Bug field, the following depositional facies are recognized: basinal, calcarenites (carbonate islands) at the platform edge; middle shelf or open platform interior; restricted inner shelf or platform interior; platform interior evaporites; and shoreline and terrestrial siliciclastic deposits.

The basinal environment represents deep water (90 to 120 feet [27-37 m]) and euxinic conditions. Lithofacies from Bug field include: (1) black to dark gray, non-calcareous, non-fossiliferous shale and silty shale; (2) spiculitic limestone; (3) pelagic lime mudstone with microfossils and occasional thin-shelled bivalves such as *Halobia*; and (4) thick, deep water siliclastic sands. The open marine lithofacies in the Cherokee field core were deposited below wave base and consist of wackestone, argillaceous limestone, and fossilferous shales containing crinoids, brachiopods, and byrozoans. The organic buildups at the platform edge from Cherokee core are represented by byrozoan-bearing packstones and wackestones.

Calcarenites are recognized in both fields and represent moderate- to high-energy, regularly agitated marine environments where shoals and/or islands developed. Sediment deposition and modification probably occurred from 5 feet (1.5 m) above sea level to 45 feet (14 m) below sea level. These platform edge deposits include: (1) oolitic and coated grain sands; (2) crinoid, foram, algal, and fusilinid sands; (3) small, benthic foram and hard peloid sands representing stabilized peloid grain flats; and (4) shoreline carbonate islands of shell hash.

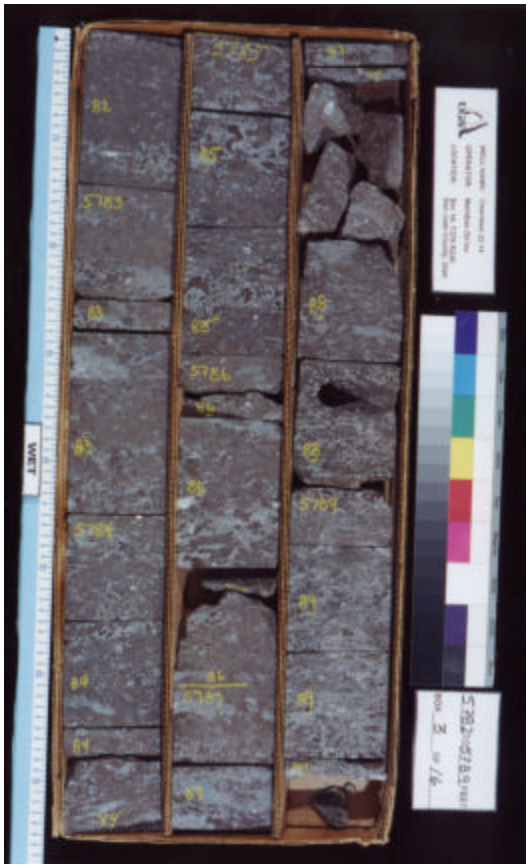


Figure 4. Photograph of representative slabbed core from the upper Ismay zone reservoir, Cherokee No. 22-14 well, Cherokee field, Utah.

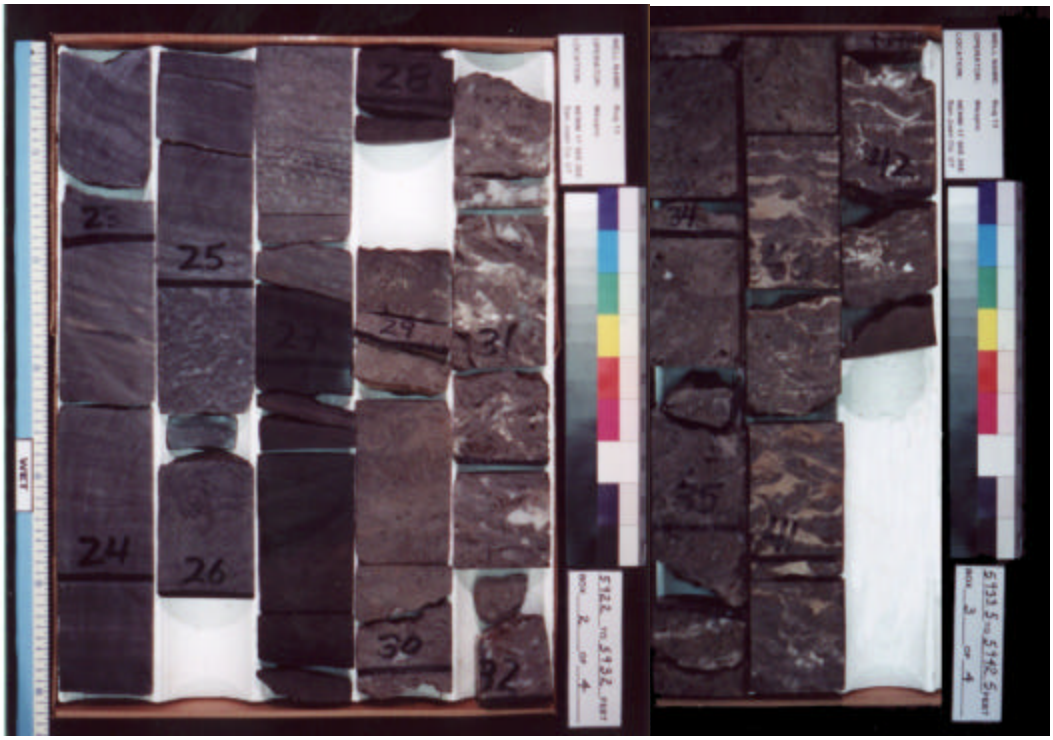


Figure 5. Photograph of representative slabbed core from the Desert Creek zone reservoir, Bug No. 13 well, Bug field, Utah.

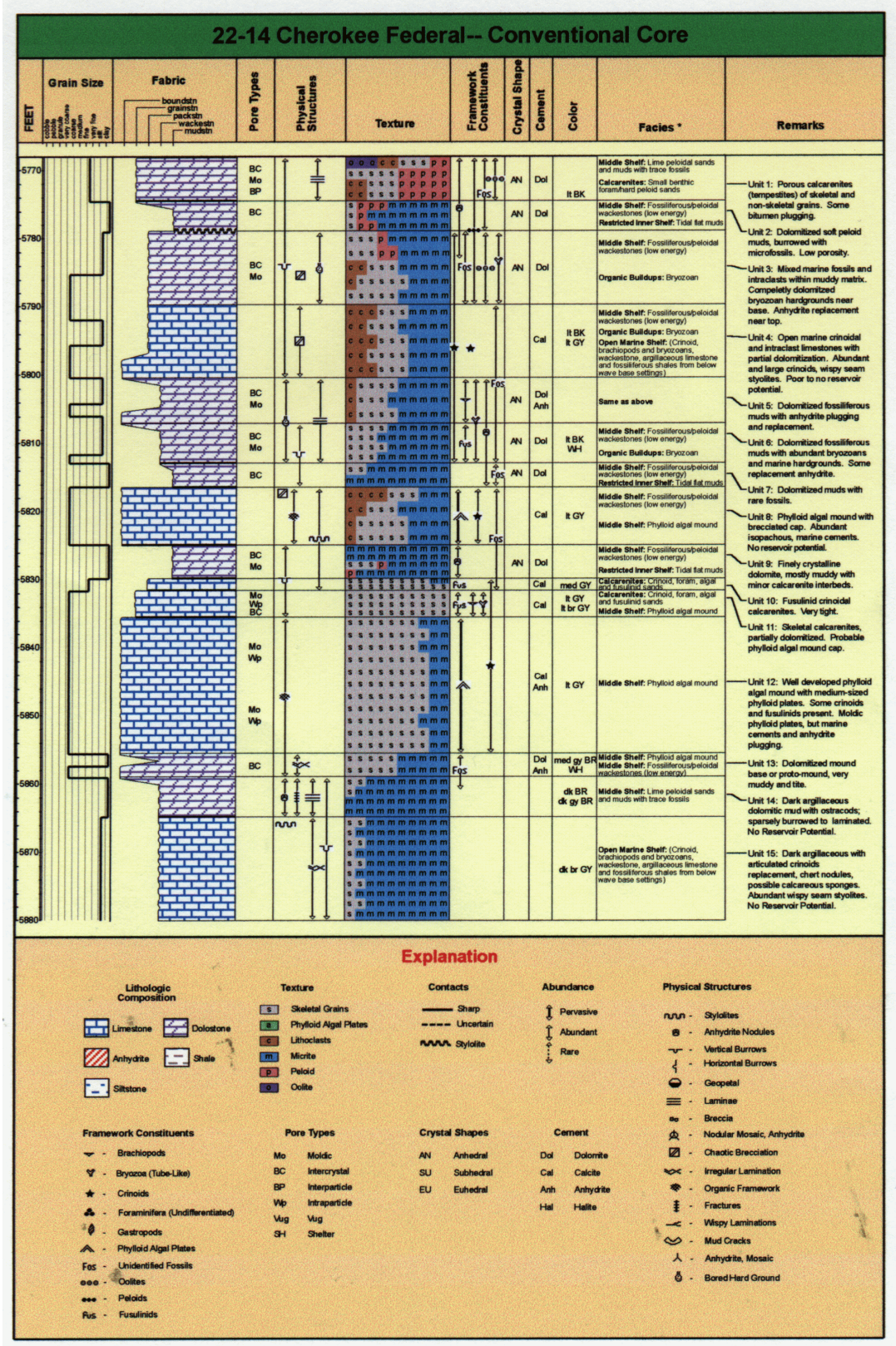


Figure 6. Core description of the upper Ismay zone, Cherokee No. 22-14 well, Cherokee field.

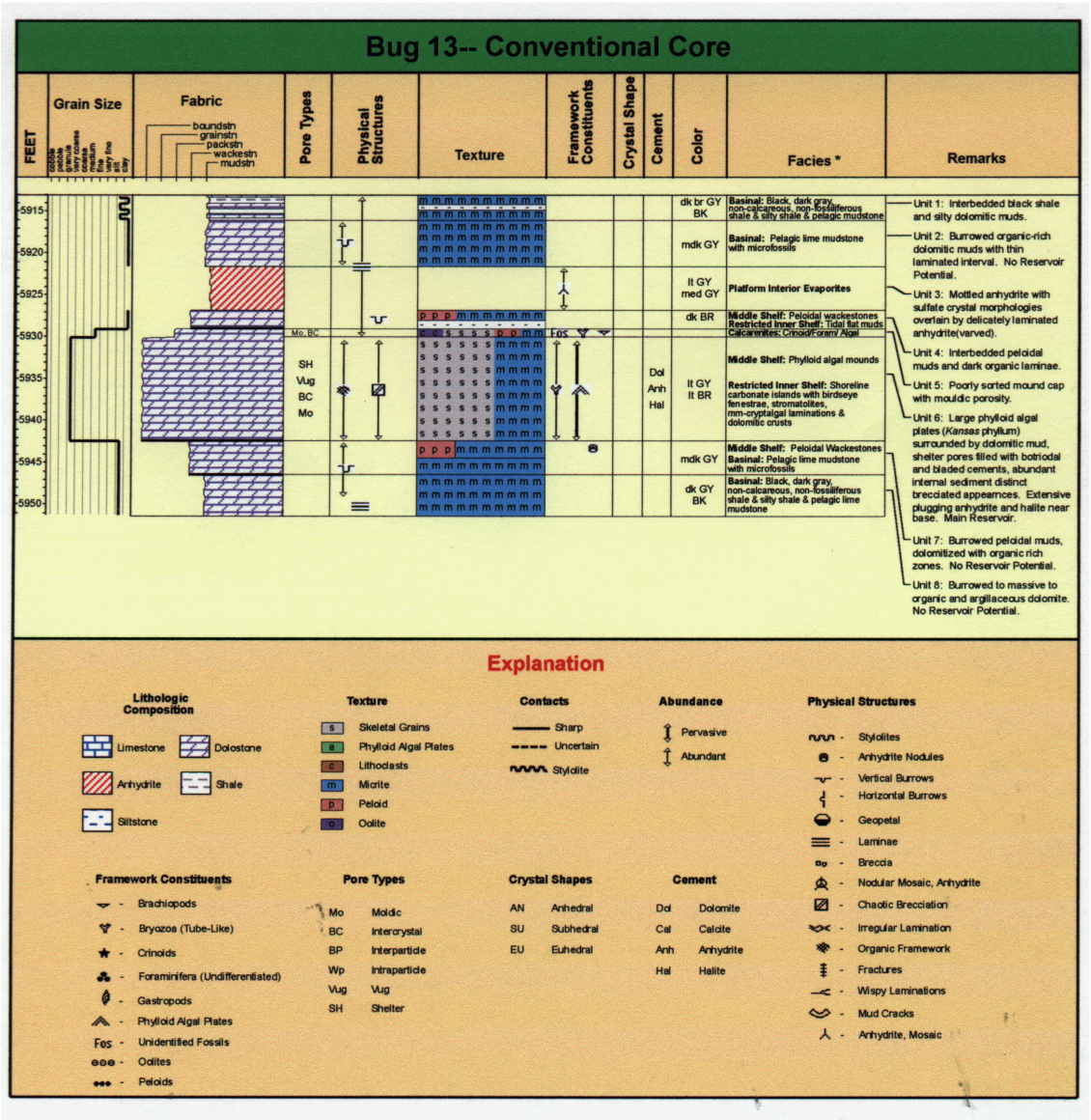


Figure 7. Core description of the Desert Creek zone, Bug No. 13 well, Bug field.

Table 1. List of well conventional slabbed core examined and described from project fields in the Paradox basin of Utah and Colorado.

Well	Location	API No.	Cored Interval (ft)	Field	Stratigraphic Zone	Samples For Thin Sections	P&P*	Repository[H]
May-Bug 2	7-36S-26E, UT	43-037-30543	6290-6333	Bug	Desert Creek	5	no	UGS
Bug 3	7-36S-26E, UT	43-037-30544	6316-6358	Bug	Desert Creek	1	no	UGS
Bug 4	16-36S-26E, UT	43-037-30542	6278-6322	Bug	Desert Creek	4	no	UGS
Bug 7A	7-36S-26E, UT	43-037-30730	6345-6400	Bug	Desert Creek	2	no	UGS
Bug 8	8-36S-26E, UT	43-037-30589	5737-5796.1	Bug	Desert Creek	0	no	UGS
Bug 10	22-36S-26E, UT	43-037-30591	6300-6346.5	Bug	Desert Creek	3	no	UGS
Bug 13	17-36S-26E, UT	43-037-30610	5913-5951.3	Bug	Desert Creek	4	no	UGS
Bug 16	17-36S-26E, UT	43-037-30607	6278-6333	Bug	Desert Creek	3	no	UGS
Cherokee 22-14	14-37S-23E, UT	43-037-31367	5768-5880	Cherokee	Ismay	17	yes	UGS
Cherokee 33-14	14-37S-23E, UT	43-037-31316	5770-5799	Cherokee	Ismay	5	yes	UGS
Little Ute 1	11-34N-20W, CO	05-083-06553	5836.0-5955.3	Sleeping Ute	Ismay	0	yes	Triple O
Sleeping Ute1	3-34N-20W, CO	05-083-06540	5533-5653	Wildcat	Ismay	0	yes	Triple O

* P&P = Porosity and permeability data from core-plug analysis.
[H] UGS = Utah Geological Survey, Salt Lake City, Utah; Triple O Slabbing, Denver, Colorado

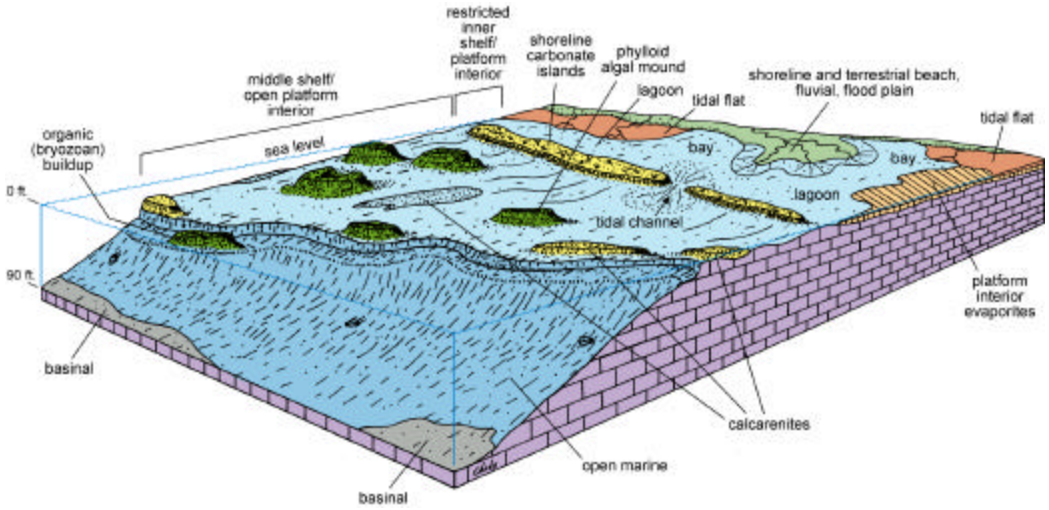


Figure 8. Block diagram displaying major depositional facies, as determined from core, for the Ismay and Desert Creek zones, Pennsylvanian Paradox Formation, Utah and Colorado.

The middle shelf or open platform interior represents a well-circulated, low- to moderate-energy, normal salinity, shallow-water (between 0 and 90 feet [0-27 m]) environment. Lithofacies from this environment form the dominant producing reservoirs in the Ismay and Desert Creek zones. Benthic forams, bivalve molluscs, and phylloid algae (*Ivanovia*) are common. Echinoderms are rare and open-marine cephalopods are generally absent. Lithofacies from Cherokee and Bug fields include: (1) limey peloidal sands and muds frequently with burrow traces; (2) fossiliferous peloidal wackstone; and (3) phylloid-algal mounds. The principal buildup process, phylloid-algal growth, occurred during high stands of sea level. Paleotopography from Mississippian-aged normal faulting produced the best marine conditions for initial algal growth.

The restricted inner shelf or platform interior represents shallow water (0 to 45 feet [0-14 m]), and generally low energy and poor circulation conditions. Fauna are limited to mainly stromatolitic algae, gastropods, certain benthic forams, and ostracods. Lithofacies include: (1) bioclastic lagoonal to bay wackestone; (2) tidal flat muds often with early dolomite; and (3) shoreline carbonate islands (productive at Bug field) with birdseye fenestrae, stromatolites, cryptoalgal laminations, and dolomitic crusts. Platform interior evaporites, usually anhydrite, were deposited in salinity restricted areas.

Shoreline and terrestrial siliciclastic deposits represent beach, fluvial, and flood-plain environments. These siliciclastic deposits include argillaceous to dolomitic siltstone with rip-up clasts, scour surfaces, or mudcracks.

Log-Based Correlation Scheme

The typical vertical sequence or cycle of depositional facies from Cherokee and Bug fields, as determined from conventional core, was tied to the corresponding gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies (figures 9, 10, and 11, and table 2). These contacts will be used to produce a variety of structure and isochore maps which will be incorporated into the reservoir models.

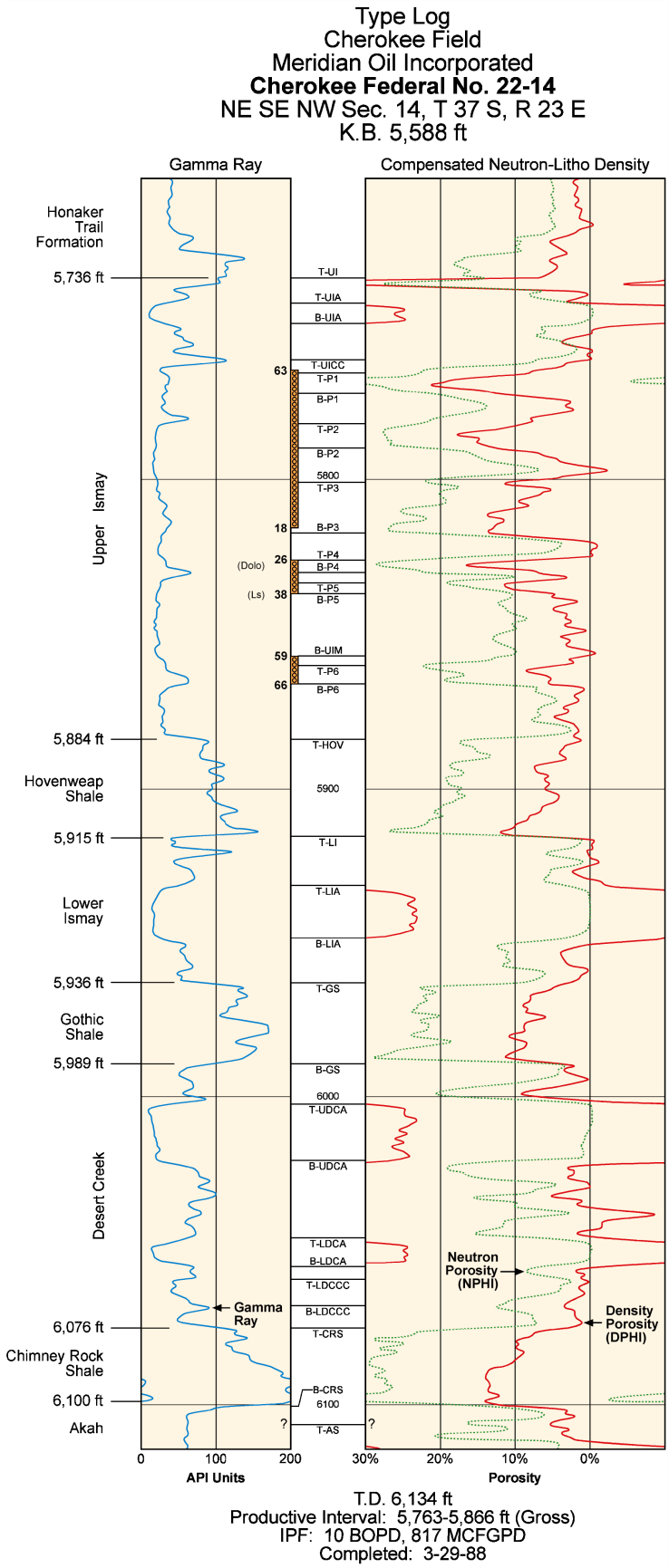


Figure 9. Type log for the Cherokee field (gamma-ray, compensated neutron-litho density) from the Cherokee Federal No. 22-14 well, showing the Ismay and Desert Creek correlation scheme, major units, and productive intervals (refer to table 2 for explanation of unit abbreviations).

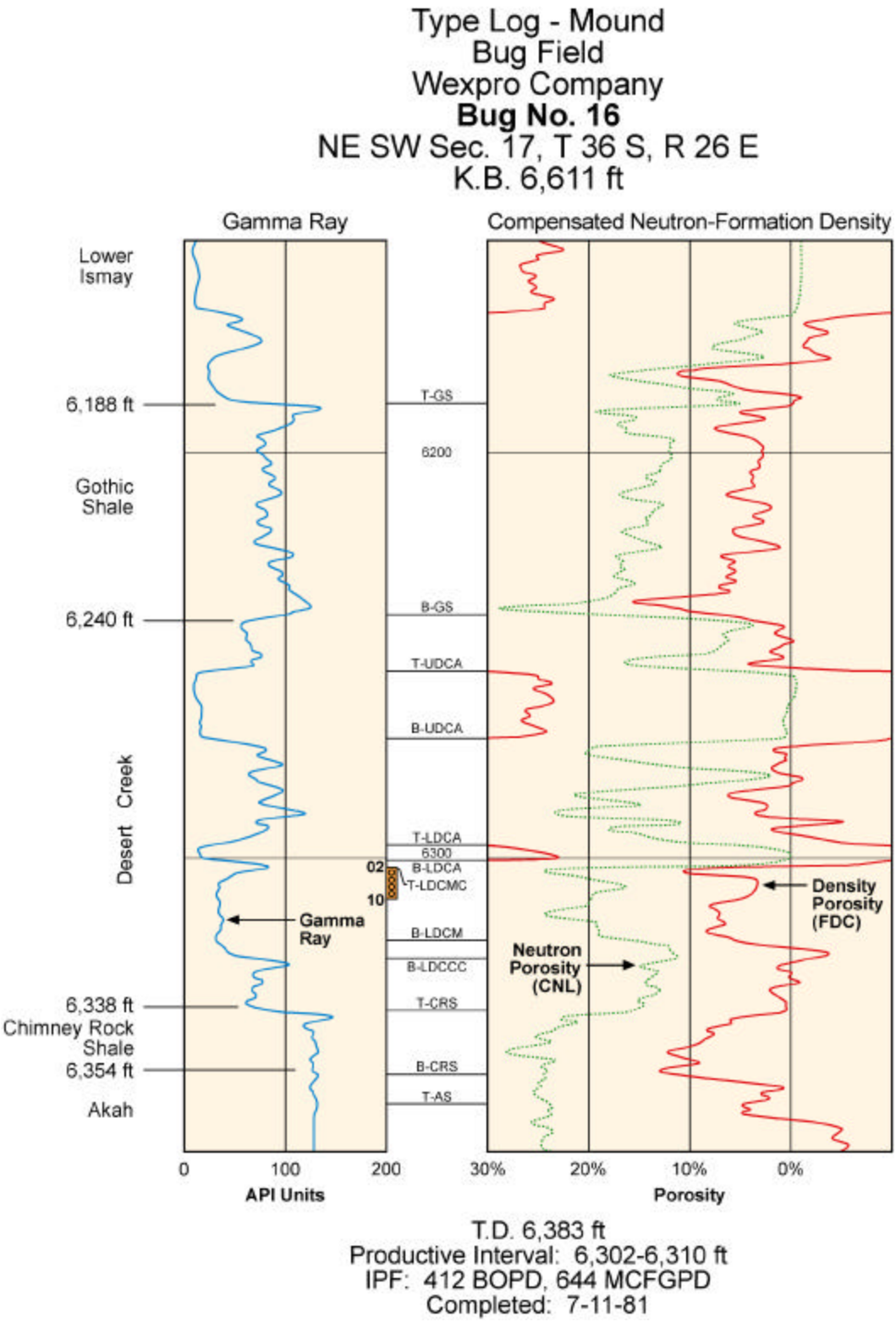


Figure 10. Type log for the Bug field mound (gamma-ray, compensated neutron-formation density) from the Bug No. 16 well, showing the Desert Creek correlation scheme, major units, and productive interval (refer to table 2 for explanation of unit abbreviations).

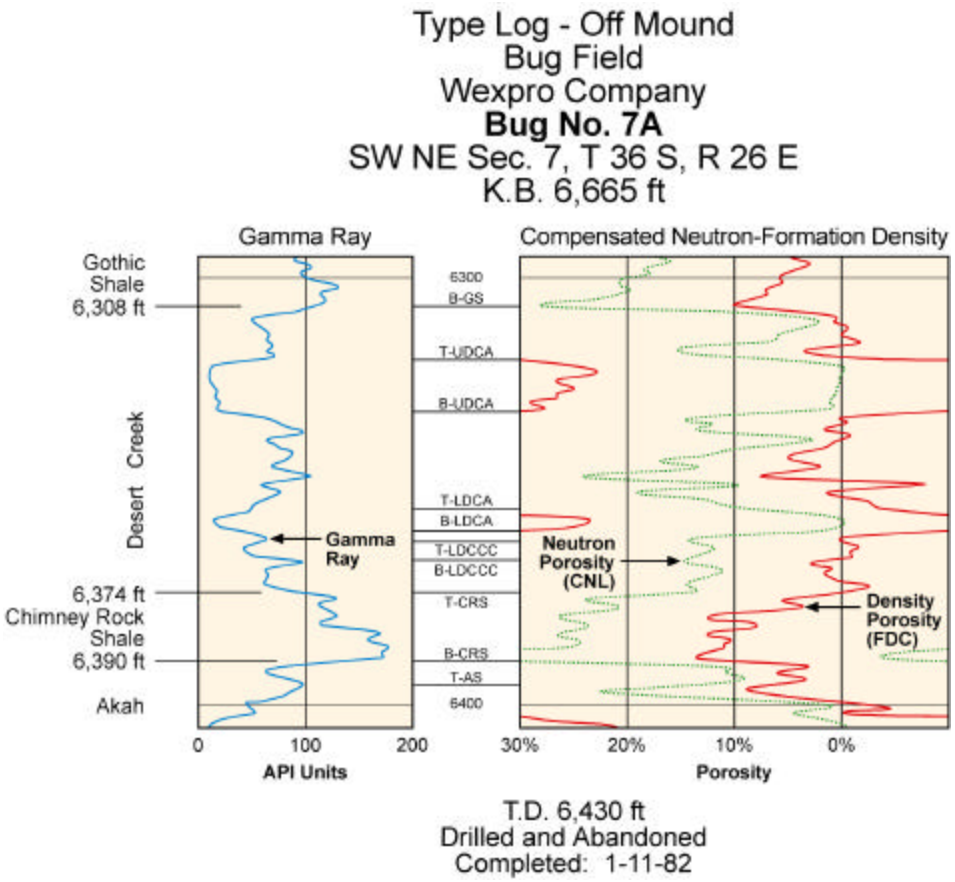


Figure 11. Type log for the Bug field off-mound area (gamma-ray, compensated neutron-formation density) from the Bug No. 7A well, showing the Desert Creek correlation scheme and major units (refer to table 2 for explanation of unit abbreviations).

Seals or barriers include anhydite layers and thick (black) shales such as the Hovenweap shale, which separates the upper Ismay from the lower Ismay. Baffles are those rock units that restrict fluid flow in some parts of the field but may develop enough porosity and permeability in other parts, through diagenetic processes or facies changes, to provide a conduit for fluid flow or even oil storage. The reservoirs are those units containing 6 percent or more porosity based on the average of the neutron and density porosity values.

Depositionally, rock units are divided into seals or barriers (anhydrites and shales), mound (carbonate buildup), and off mound. Porosity units, reservoir or potential reservoir layers, are identified within the mound and off-mound intervals. The mound and some of the off-mound units are part of the clean carbonate - an interval where carbonate mudstone and shale are generally absent. The top and base of all these intervals (seals, mound, clean carbonate, as well as porosity units) are determined and coded as listed on table 2. The unlisted intervening units represent the baffles or non-reservoir rocks such as non-porous packestone or wackestone. The mound/mound cap intervals usually have porosity greater than 6 percent while the clean carbonate intervals are defined by lithology only (such as bafflestone or grainstone), although there may be occasional isolated porosity zones. The top and base of the mound/mound cap intervals are often equivalent to the clean top and base of the clean carbonate intervals. In addition, the top and base of the mound/mound cap intervals may be equivalent to the top and base of the thinner off-mound clean carbonate intervals.

Table 2. Correlation scheme used for Ismay and Desert Creek zones of the Paradox Formation in Cherokee and Bug fields, Blanding sub-basin, Utah.

Unit Code	Description
T-UI	Top - Upper Ismay Zone
T-UIA	Top - Upper Ismay Anhydrite
B-UIA	Base - Upper Ismay Anhydrite
T-UICC	Top - Upper Ismay Clean Carbonate
T-P1	Top - Porosity Unit #1
B-P1	Base - Porosity Unit #1
T-P2	Top - Porosity Unit #2
B-P2	Base - Porosity Unit #2
T-P3	Top - Porosity Unit #3
B-P3	Base - Porosity Unit #3
T-P4	Top - Porosity Unit #4
B-P4	Base - Porosity Unit #4
T-P5	Top - Porosity Unit #5
B-P5	Base - Porosity Unit #5
B-UIM	Base - Upper Ismay Mound
B-UICC	Base Upper Ismay Clean Carbonate
T-P6	Top - Porosity Unit #6
B-P6	Base - Porosity Unit #6
T-HOV	Top - Hovenweap Shale
T-LI	Top - Lower Ismay Zone
T-LIA	Top - Lower Ismay Anhydrite
B-LIA	Base - Lower Ismay Anhydrite
T-GS	Top - Gothic Shale
B-GS	Base - Gothic Shale
T-UDCA	Top - Upper Desert Creek Anhydrite
B-UDCA	Base - Upper Desert Creek Anhydrite
T-LDCA	Top - Lower Desert Creek Anhydrite
B-LDCA	Base - Lower Desert Creek Anhydrite
T-LDCMC	Top - Lower Desert Creek Mound Cap
B-LDCM	Base - Lower Desert Creek Mound
T-LDCCC	Top - Lower Desert Creek Clean Carbonate
B-LDCCC	Base - Lower Desert Creek Clean Carbonate
T-CRS	Top - Chimney Rock Shale
B-CRS	Base - Chimney Rock Shale
T-AS	Top - Akah Subaerial

In Cherokee field, six porosity units were identified, five of which occur in the upper Ismay mound and the other one in the lower part of clean carbonate. In Bug field, the porosity unit is the entire mound. Several units in Cherokee field exhibit a "false porosity" on geophysical logs which led the operator to perforate the interval and attempt a completion. The cores, however, reveal these zones to actually represent barriers or baffles to fluid flow.

The correlation scheme will be used for: (1) predicting changes in reservoir and non-reservoir rocks across the field, (2) comparing field to non-field areas, (3) estimating the reservoir properties and identifying facies in wells which were not cored, and (4) determining potential units suitable for horizontal drilling projects. It can be applied to other fields in the Blanding sub-basin, both those with cores and without.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for five government-industry cooperative petroleum-research projects including two in the Paradox basin. These projects are designed to improve recovery, development, and exploration of the nation's oil and gas resources through use of better, more efficient technologies. The projects involve detailed geologic and engineering characterization of several complex heterogeneous reservoirs. The two Class II Paradox basin (this report cover the Class II Revisit project) and the Class I Bluebell field (Uinta Basin) projects include practical oil-field demonstrations of selected technologies. The fourth project involves geological characterization and reservoir simulation of the Ferron Sandstone on the west flank of the San Rafael uplift as a surface analogue of a fluvial-dominated, deltaic reservoir. The fifth project involves establishing a log-based correlation scheme for the Tertiary Green River Formation in the southwestern Uinta Basin to help identify new plays and improve the understanding of producing intervals. The DOE and multidisciplinary teams from petroleum companies, petroleum service companies, universities, private consultants, and state agencies are co-funding the five projects.

The UGS will release all products of the Paradox basin project in a series of formal publications. These will include all the data as well as the results and interpretations. Syntheses and highlights will be submitted to refereed journals as appropriate, such as the *American Association of Petroleum Geologists (AAPG) Bulletin* and *Journal of Petroleum Technology*, and to trade publications such as the *Oil and Gas Journal*. This information will also be released through the UGS periodicals *Petroleum News, Survey Notes*, and on the project Internet home page.

A Technical Advisory Board of twelve oil company operators from the Paradox basin was established. The Technical Advisory Board will advise the technical team on the direction of study, review technical progress, recommend changes and additions to the study, and provide data. The Technical Advisory Board ensures direct communication of the study methods and results to the Paradox basin operators. A Stake Holders Board was also established and is composed of groups that have a financial interest in the study area including representatives from the Utah and Colorado state governments (Utah School and Institutional Trust Lands Administration, Utah Division of Oil, Gas and Mining, and Colorado Oil and Gas Conservation Commission), Federal Government (U.S. Bureau of Land Management and U.S. Bureau of Indian Affairs), and the Ute Mountain Ute Indian Tribe. The members of the Technical Advisory and Stake Holders Boards receive all quarterly and annual technical reports and

copies of all publications resulting from the study. Stake Holders Board meetings and/or meetings with individual Stake Holders will be held as needed. Technical team members met with the Technical Advisory and Stake Holders Boards in Denver, Colorado, and Salt Lake City, Utah, at the beginning of the project to present project goals and benefits, obtain available technical data, and hear initial feedback or advice.

Project materials, plans, and objectives were displayed at the UGS booth during the AAPG annual national convention, April 16-19, 2000, in New Orleans, Louisiana. Three UGS scientists staffed the display booth at this event. Project displays will be included as part of the UGS booth at professional meetings throughout the duration of the project.

An abstract was submitted to the AAPG, and accepted, on heterogeneous carbonate buildups in the Blanding sub-basin as targets for horizontal drilling techniques. The paper will be presented at a special poster session (where core will be displayed) on Rocky Mountain reservoirs during the 2001 AAPG annual national convention in Denver, Colorado.

Utah Geological Survey *Petroleum News, Survey Notes,* and Internet Web Sites

The purpose of the UGS *Petroleum News* newsletter is to keep petroleum companies, researchers, and other parties involved in exploring and developing Utah's energy resources, informed of the progress on various energy-related UGS projects. *Petroleum News* contains articles on: (1) DOE-funded and other UGS petroleum project activities, progress, and results; (2) current drilling activity in Utah including coalbed methane development; (3) new acquisitions of well cuttings, core, and crude oil at the UGS Geological Sample Library; and (4) new UGS petroleum publications. The purpose of *Survey Notes* is to provide nontechnical information on contemporary geologic topics, issues, events, and ongoing UGS projects to Utah's geologic community, educators, state and local officials and other decision makers, and the public. *Survey Notes* is published three times yearly and *Petroleum News* is published annually. Single copies are distributed free of charge and reproduction (with recognition of source) is encouraged. The UGS maintains a database that includes those companies or individuals specifically interested in the Paradox basin project (more than 300 as of September 2000) or other DOE-sponsored projects.

The UGS and the CGS maintain web sites on the Internet, http://www.ugs.state.ut.us/ and http://www.dnr.state.co.us/geosurvey. The UGS site includes a page under the heading *Economic Geology Program*, which describes the UGS/DOE cooperative studies (Paradox basin, Ferron Sandstone, Bluebell field, Green River Formation), contains the latest issue of *Petroleum News*, and has a link to the U.S. Department of Energy web site. Each UGS/DOE cooperative study also has its own separate page on the UGS web site (figure 12). The Paradox basin project page http://www.ugs.state.ut.us/paradox2.htm contains: (1) a project location map, (2) a description of the project, (3) a list of project participants and their postal addresses and phone numbers, (4) a reference list of all publications that are a direct result of the project, and (5) semi-annual technical progress reports. The CGS web site contains the same project information.

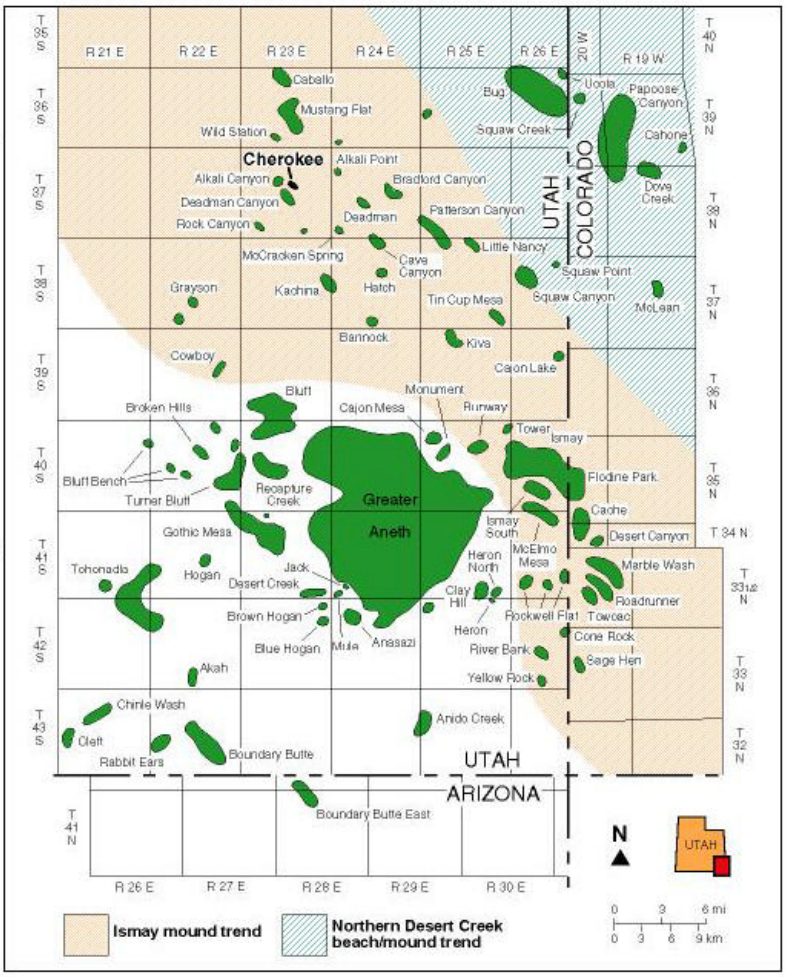
Paradox Basin II - DOE Class II Oil Revisit

Heterogeneous Shallow-shelf Carbonate Buildups in the Blanding Sub-basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques

The Paradox Basin, which extends from Utah into portions of Colorado and Arizona, contains more than 75 small oil fields, each capable of producing 2 to 10 million barrels of oil. But variations in the reservoirs of these fields prevent recovery of up to 75 percent of that resource, using conventional extraction methods.

This new 5-year study will evaluate methods to extract as much as another 50 million barrels of oil from existing wells in the basin. It will consist of a geologic and reservoir characterization study of the Ismay and Desert Creek zones of the 300-million-year-old Paradox Formation. The goal will be to determine if horizontal drilling techniques can increase well productivity from thin, untested intervals of reservoir rock. Cherokee field in San Juan County will be a target for a detailed case study.

The total cost of the project will be $1.03 million. Funding will come from the U.S. Department of Energy, the Utah Geological Survey, the Colorado Geological Survey, and private industry. The management and technical team, headed by UGS Principal Investigator Thomas C. Chidsey, Jr., will include Seeley Oil Company of Salt Lake City, the Colorado Geological Survey, and Eby Petrography & Consulting, Inc.



Utah Geological Survey
Project Home Page Internet Address

http://www.ugs.state.ut.us/paradox2/paradox2/htm

Reports

- Abstract
- Statement of Work

For more information on the Paradox Basin II Project, contact Tom Chidsey, (801) 537-3364, email: nrugs.tchidsey@state.ut.us.

Figure 12. The Paradox basin project page, http://www.ugs.state.ut.us/paradox2.htm, from the UGS Internet web site.

Presentations

The following technical presentations were made during the first six months of the project as part of the technology transfer activities. These presentations described the project in general and gave detailed information on the reservoir characterization, exploration trends, project goal and benefits.

"Class II Oil Revisit Project - Heterogeneous Shallow-Shelf Carbonate Buildups in the Blanding Sub-Basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques" by Laura Wray, U.S. Department of Energy, Contractors Review Meeting, Denver, Colorado, June 28, 2000.

"Heterogeneous Shallow-Shelf Carbonate Buildups in the Blanding Sub-Basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques" by David E. Eby, 10th Annual National Indian Energy & Minerals Conference sponsored by the Bureau of Indian Affairs, Colorado School of Mines, Golden, Colorado, June 21, 2000.

CONCLUSIONS

The Blanding sub-basin within the Pennsylvanian Paradox basin developed on a shallow-marine shelf that locally contained algal-mound and other carbonate buildups. The two main producing zones of the Paradox Formation are the Ismay and the Desert Creek. The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material. The Ismay is productive in fields of the southern Blanding sub-basin. The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts. Two Utah fields were selected for evaluation on a local scale: Cherokee in the Ismay trend and Bug in the Desert Creek trend.

The depositional environments of the Ismay and Desert Creek zones, based on the core descriptions, show that the controlling factors were water depth, salinity, prevailing wave energy, and in the case of phylloid-algal growth, paleostructural position. Depositional facies include: basinal, open marine shelf, open marine organic buildups, calcarenites at the platform edge (including carbonate islands), middle shelf or open platform interior, restricted inner shelf or platform interior evaporites, and shoreline and terrestrial siliciclastic deposits. Lithofacies from the middle shelf or open platform interior, principally the phylloid-algal mounds, form the dominant producing reservoirs in the Ismay and Desert Creek zones.

The log-based correlation scheme developed for the project ties the typical vertical sequence or cycle of depositional facies from Cherokee and Bug fields, as determined from conventional core, to their corresponding gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. Seals or barriers include anhydrite layers and shales. Baffles are those rock units that restrict fluid flow in some parts of the field, but may develop enough porosity and permeability in other parts through diagenetic processes or facies changes to provide a conduit for fluid flow or even oil storage.

From the initial observations made during core description, the reservoir quality of Cherokee and Bug fields has been affected by multiple generations of dissolution, anhydrite plugging, and various types of cementation which act as barriers or baffles to fluid flow. In Cherokee field, six porosity units were identified in the upper Ismay zone. In Bug field, the porosity unit is the entire Desert Creek mound. However, geophysical logs often exhibit a "false porosity" for some units which led to wasteful completion attempts. The cores reveal these zones to actually represent barriers or baffles to fluid flow. Actual porosity units represent potential targets for horizontal drilling and warrant further investigation.

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